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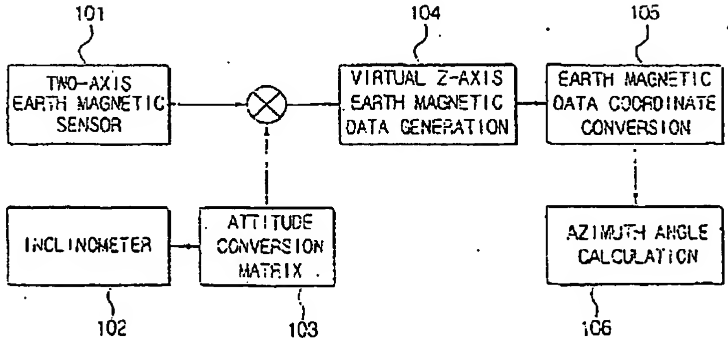
(54) Apparatus and method for calculating azimuth angle

(57) An apparatus and method of compensating for the change of an earth magnetic sensor output according to an attitude (roll and pitch) using an inclinometer in the case of calculating azimuth information using a two-axis earth magnetic sensor is disclosed. The attitude of the earth magnetic sensor module is measured using the inclinometer, and a coordinate conversion matrix for converting a body coordinate system to a horizontal coordinate system is calculated. Z-axis direction virtual earth magnetic data at the present attitude of the earth magnetic sensor module is generated using the output of the two-axis earth magnetic sensor and the calculated attitude information. After the generated Z-axis earth magnetic data and the measured X-axis and Y-axis earth magnetic data are converted into the horizontal coordinate system, the calculated azimuth angle is considered as the azimuth angle of the earth magnetic sensor module.

FIG. 1



Description

[0001] The present invention relates to a measurement apparatus and calculation method which can calculate accurate azimuth information.

[0002] Up to now, there have been efforts to provide a method and apparatus for calculating azimuth information of a vehicle or a sensor module which moves in free space using an earth magnetic sensor such as a fluxgate. However, since the fluxgate is expensive and large-sized, it has been used only for navigation.

[0003] Recently, small-sized and low cost earth magnetic sensor modules have been developed, and especially, with the development of MEMS technology, chip type earth magnetic sensor modules have been developed and used in diverse fields which require azimuth information. However, in the application fields where the earth magnetic sensor module cannot be leveled, accurate azimuth information cannot be obtained only through the earth magnetic sensor.

[0004] Generally, the earth magnetic sensor is a device for measuring the strength of the earth magnetic field, and it can measure the strength of the magnetic field accurately only in the case that a flux vector of the earth magnetic field is parallel to a vector of a measurement axis of the sensor for measuring the flux vector. In this case, when a two-axis earth magnetic sensor in which each axis is orothogonally arranged with a right-hand rule, is horizontally mounted to form a sensor module, the azimuth angle indicated by the sensor module is calculated using outputs of the two sensors.

[0005] However, if the earth magnetic sensor module cannot be leveled, the strength of the earth magnetic field cannot accurately be measured, and the azimuth information at this time may include a great error. Consequently, the error according to an attitude should be compensated for, and for this, an error compensation through a coordinate conversion is performed using a three-axis earth magnetic sensor and an inclinometer for measuring the attitude.

[0006] With the development of a small-sized earth magnetic sensor, the attitude error compensation technique expands its application fields to sports, multimedia, game machine, etc.

[0007] However, in the case of using the two-axis earth magnetic sensor due to the problems of a sensor installation space, the error cannot be compensated for only through the developed error compensation technique, and thus the azimuth angle calculated increases in error according to the size of the attitude.

[0008] According to a first aspect of the invention, there is provided an apparatus for calculating an azimuth angle, comprising a two-axis earth magnetic sensor, mounted on a device which requires azimuth information, for measuring a strength of an earth magnetic field, a two-axis inclinometer for providing attitude information (such as roll and pitch angle), a signal conditioning unit for filtering a signal measured by the sensor and converting the filtered signal into a digital value, a microprocessor for calculating the azimuth angle using the strength of the earth magnetic field measured by the earth magnetic sensor and an output of the inclinometer, an LCD module for displaying the calculated azimuth information, and a serial communication interface for transmitting the sensed signal processed by the microprocessor and the calculated azimuth information.

[0009] According to a second aspect of the invention, there is provided an apparatus for calculating an azimuth angle, comprising a two-axis earth magnetic sensor; a two-axis inclinometer and means for calculating an attitude using an output of the inclinometer, and for calculating azimuth by compensating for an attitude error of the two-axis earth magnetic sensor.

[0010] The invention can thus compensate for an attitude error of an earth magnetic sensor using information on an earth magnetic field obtained from a two-axis earth magnetic sensor and an inclinometer. Accurate azimuth information can then be obtained.

[0011] The invention also provides a method of calculating an azimuth angle, comprising the steps of setting a data output period using an internal timer mounted on a microcomputer, converting an analog value sensed by a sensor into a digital value, storing the converted sensor data in an internal register of the microprocessor, calculating a coordinate conversion matrix using inclinometer data, generating a virtual Z-axis earth magnetic data, calculating earth magnetic data on a horizontal coordinate system using a three-axis earth magnetic data (i.e., the two-axis earthy magnetic sensor data plus the one-axis virtual sensor data) and the coordinate conversion matrix, calculating the azimuth angle using the calculated data, and if a timer interrupt is generated due to the output period set in the internal timer, transmitting the sensor data and the calculated azimuth data to an external system through a serial communication and displaying the sensor data and the calculated azimuth data on an LCD module.

[0012] The apparatus and method of the invention enables accurate azimuth information to be calculated by compensating for an attitude error of a two-axis earth magnetic sensor. In the case that the two-axis earth magnetic sensor is mounted on a device which requires the azimuth information (for example, a navigation system, game machine, PDA, cellular phone, etc.), the apparatus and method according to the present invention can calculate the attitude information using a two-axis inclinometer, and then compensates for the error according to the attitude of the earth magnetic sensor to obtain the accurate azimuth information.

[0013] An algorithm for obtaining the coordinate conversion matrix for converting the earth magnetic sensor data into the horizontal coordinate system may comprise converting a unit of the inclinometer data stored in the internal

register of the microprocessor into an SI unit by multiplying the inclinometer data by a scale factor, calculating an attitude using the converted inclinometer data, and calculating the coordinate conversion matrix using the calculated attitude value.

[0014] An algorithm for generating the virtual Z-axis earth magnetic data in the case of using the two-axis earth magnetic sensor may comprise setting earth magnetic data measured when the earth magnetic sensor points to a vertically downward direction of the earth, and generating the virtual Z-axis earth magnetic data using the calculated attitude information and the X-axis and Y-axis earth magnetic data.

[0015] Preferred embodiments of the invention will now be described in detail with reference to the attached drawings in which:

FIG. 1 is a view illustrating a method of calculating an azimuth angle by compensating for an attitude error by a two-axis earth magnetic sensor according to the present invention;

FIG. 2 is a view illustrating the construction of a two-axis earth magnetic sensor and an attitude error compensation apparatus according to the present invention;

FIG. 3 is a flowchart illustrating the operation of the microprocessor mounted on the two-axis earth magnetic sensor and an attitude error compensation apparatus according to the present invention;

FIG. 4 is a graph illustrating the experimental result of the attitude calculated using the inclinometer according to the present invention;

FIG 5 is a graph illustrating the experimental result of the virtual Z-axis earth magnetic data calculated using the two-axis earth magnetic sensor and the inclinometer; and

FIG. 6 is a graph illustrating the experimental result of the azimuth angle calculated using the two-axis earth magnetic sensor and the inclinometer.

[0016] An apparatus and method of calculating an azimuth angle according to preferred embodiments of the present invention will now be described in detail with reference to the annexed drawings in which like reference numerals refer to like elements.

[0017] FIG. 1 is a view illustrating a method of calculating an azimuth angle by compensating for an attitude error by a two-axis earth magnetic sensor according to the present invention. The method includes a two-axis earth magnetic sensor 101, an inclinometer 102, an attitude (e.g., coordinate) conversion matrix 103, a virtual Z-axis earth magnetic data generation 104, a earth magnetic data coordinate conversion 105, and an azimuth angle calculation 106.

[0018] The earth magnetic sensor 101, which may be a fluxgate sensor or a magnetoresistive (MR), measures the strength of the earth magnetic field, and comprises a two-axis earth magnetic sensor having an X-axis in the forward direction of the sensor module and Y-axis in the rightward direction from the X-axis at an angle of 90°.

[0019] The inclinometer 102 measures a tilt angle of the sensor 101 with respect to the earth surface, and an accelerometer may be used as the inclinometer. In the case that the accelerometer, which measures only the acceleration of gravity at a standstill, is used as the inclinometer, the attitude information can be calculated by measuring the accelerations of different levels according to the attitude using the two-axis or three-axis module arranged at right angles. In the case of using the two-axis accelerometer, the acceleration is measured through Equations 1a and 1b and the attitude is calculated using Equations 2a and 2b.

$$a_x = g \cdot \sin\theta \tag{Ia}$$

$$a_y = g \cdot \sin\phi \tag{Ib}$$

$$\phi = \sin^{-1}(\alpha_y / g) \tag{2a}$$

$$\theta = \sin^{-1}(\alpha_x / g) \tag{2b}$$

[0020] Here, a_x and a_y are output values of the X-axis and Y-axis accelerometer, g is the acceleration of gravity, and ϕ and θ are a roll and a pitch angle, respectively.

[0021] The coordinate conversion matrix 103 is for converting the earth magnetic sensor data into the horizontal coordinate system, and is constructed as follows using the attitude information calculated using the output value of the inclinometer 102.

$$C_b^h = \begin{bmatrix} \cos\theta & \sin\theta\sin\phi & \sin\theta\cos\phi \\ 0 & \cos\phi & -\sin\phi \\ -\sin\theta & \cos\theta\sin\phi & \cos\theta\cos\phi \end{bmatrix} \quad (3)$$

[0022] The virtual Z-axis earth magnetic data 104 is for the attitude error compensation of the two-axis earth magnetic sensor, and is calculated as follows using the two outputs of the earth magnetic sensor and the attitude information as calculated above.

$$Z_{jg} = \frac{Z_h + X_{jg}\sin\theta - Y_{jg}\sin\phi\cos\theta}{\cos\phi\cos\theta} \quad (4)$$

[0023] Here, Z_h is the strength of the earth magnetic field first measured by experiment when a measurement axis of the earth magnetic sensor points to a vertically downward direction of the earth.

[0024] The coordinate conversion 105 of the earth magnetic sensor data to the horizontal coordinate system is performed as follows.

$$\begin{bmatrix} X_h \\ Y_h \\ Z_h \end{bmatrix} = C_b^h \begin{bmatrix} X_{jg} \\ Y_{jg} \\ Z_{jg} \end{bmatrix} \quad (5)$$

[0025] Here, $[X_{jg}\ Y_{jg}\ Z_{jg}]^T$ is the earth magnetic sensor data.

[0026] The azimuth calculation 106 is performed as follows using the earth magnetic data the coordinate of which is converted into the horizontal coordinate system.

$$\phi = \tan^{-1}(Y_h / X_h) \quad (6)$$

[0027] FIG. 2 is a view illustrating the construction of an interface for a two-axis earth magnetic sensor constructed to perform the function of FIG. 1. The interface includes a two-axis earth magnetic sensor 201, an inclinometer 202, a signal conditioning unit 203, a microprocessor 204, an LCD module 205, and a serial communication interface 206.

[0028] The signal conditioning unit 203 comprises a low-pass filter for removing a power supply noise and a high-frequency noise, and an analog-to-digital (A/D) converter for converting the analog sensor signal into a digital value. The signal conditioning unit 203 is necessary to process the sensor signal before it is inputted to the microprocessor 204.

[0029] The microprocessor 204 comprises a register for storing the sensor signal outputted from the A/D converter 203, an ALU (Arithmetic Logic Unit) and an FPU (Floating Point Unit) for compensating for the attitude error of the earth magnetic sensor and calculating the azimuth information, and an internal timer for setting an output period for transmitting the sensor data and the calculated azimuth information to the LCD module and the external device.

[0030] The LCD module 205 displays the azimuth information outputted from the microprocessor 204, so that the user can recognize the azimuth angle of the device having the earth magnetic sensor module mounted thereon.

[0031] The serial communication interface 206 is for transmitting the sensor data and the azimuth information outputted from the microprocessor 204 to the external device, and it may adopt asynchronous serial communication or synchronous serial communication type.

[0032] FIG. 3 is a flowchart illustrating the operation of the microprocessor mounted on the two-axis earth magnetic sensor and an attitude error compensation apparatus according to the present invention.

[0033] First, in order to transmit the output values of the two-axis earth magnetic sensor 201 and the inclinometer 202 and the finally calculated azimuth information to the external system, the data output period is set using the internal

timer mounted on the microcomputer 204 (step 301).

[0034] In order to convert the output values of the earth magnetic sensor 201 and the inclinometer 202 into digital values, an A/D converter control signal is produced (step 302), and then the converted sensor data is stored in the internal register (step 303).

[0035] The attitude of the sensor module is calculated through Equations 2a and 2b using the inclinometer data among the stored sensor data (step 304). Using this calculated attitude, the coordinate conversion matrix is calculated through Equation 3 (step 305).

[0036] The virtual Z-axis earth magnetic data is generated through Equation 4 using the calculated attitude and the earth magnetic sensor data stored in the internal register (step 306).

[0037] The three-axis earth magnetic data (i.e., two-axis earth magnetic sensor data + one-axis calculated virtual Z-axis earth magnetic data) is converted into the strength of the earth magnetic field in the horizontal coordinate system through Equation 5 using the calculated coordinate conversion matrix (step 307). Using this converted data, the azimuth angle is calculated through Equation 6 (step 308).

[0038] It is searched whether an interrupt is generated by the data output period set in the internal timer (step 309).

[0039] If it is searched that the timer interrupt is not generated, the present step returns to the previous step 302 of converting the sensor data into the digital value to repeat the performing of the step 302. Meanwhile, if it is searched that the timer interrupt is generated (step 309), the azimuth information calculated as above and the sensor data are transmitted to the external system using the serial communication (step 310), and outputted to the LCD module for display (step 311). After that, the operation returns to the step 302 of converting sensor data into digital value and repeats the steps thereafter until the next timer interrupt is generated.

[0040] FIG. 4 is a graph illustrating the experimental result of the attitude calculated through Equation 2 using the inclinometer 202 according to the present invention.

[0041] FIG. 5 is a graph illustrating the experimental result of the virtual Z-axis earth magnetic data calculated through Equation 4 in comparison to the Z-axis of the three-axis earth magnetic sensor. In FIG. 5, the dotted line represents the Z-axis of the three-axis earth magnetic sensor, and the solid line represents the virtual Z-axis earth magnetic data calculated through Equation 4. It can be recognized that the Z-axis earth magnetic data, which varies according to the change of the attitude, is accurately generated through Equation 4.

[0042] FIG. 6 is a graph illustrating the experimental result of the azimuth angle calculated through Equations 5 and 6 using the generated virtual Z-axis earth magnetic data, the output of the two-axis earth magnetic sensor, and the calculated coordinate conversion matrix in the case that the attitude is changed. The dotted line represents the uncompensated azimuth angle, which shows a great change of the azimuth angle, while the solid line represents the compensated azimuth angle, which shows that the azimuth angle is changed only within an error range where the change of the azimuth angle is small.

[0043] According to the apparatus for calculating the azimuth angle by the attitude error compensation of the earth magnetic sensor according to the present invention, the azimuth information is provided to the user using a two-axis earth magnetic sensor and a two-axis inclinometer, and overcoming the technical limit of the two-axis earth magnetic sensor module. This avoids the need for existing three-axis earth magnetic sensors with the inclinometer.

[0044] The present invention can be conveniently used in any situation when the azimuth information is required. For example, when it is intended to confirm the user's heading direction using an electronic map stored in a PDA, the present accurate azimuth angle of the user is recognized and the map is rotated accordingly to be displayed on the LCD of the PDA, so that the user can conveniently determine his/her own heading direction.

[0045] Also, the present invention facilitates the implementation of the three dimensional game through the information on the rotating direction of the game machine in addition to the attitude of the game machine, and further it can used as the data input device of the virtual reality.

[0046] While the present invention has been described in detail, it should be understood that various changes; substitutions and alterations can be made hereto without departing from the scope of the invention as defined by the appended claims.

Claims

1. An apparatus for calculating an azimuth angle, comprising:

    a two-axis earth magnetic sensor, mounted on a device which requires azimuth information, for measuring a strength of an earth magnetic field according to the azimuth information if the device moves;
    an inclinometer used for calculating an attitude such as a roll and a pitch angle;
    an analog-to-digital (A/D) converter for converting sensor data into a digital value;
    a microprocessor for calculating the azimuth information by compensating for an attitude error using outputs

of the two-axis earth magnetic sensor and the inclinometer;
a serial communication interface for transmitting the data processed by the microprocessor; and
an LCD module for displaying the azimuth information calculated by the microprocessor.

2. An apparatus for calculating an azimuth angle, comprising:

a two-axis earth magnetic sensor;
a two-axis inclinometer; and
means for calculating an attitude using an output of the inclinometer, and for calculating azimuth by compensating for an attitude error of the two-axis earth magnetic sensor.

3. An apparatus for compensating for an attitude error of a two-axis earth magnetic sensor, comprising:

an input for receiving data from a two-axis earth magnetic sensor;
an input for receiving data from a two-axis inclinometer; and
means for calculating an attitude using an output of the inclinometer, and for compensating for an attitude error of the two-axis earth magnetic sensor.

4. A method of calculating an azimuth angle, comprising:

a first step of setting a data output period using an internal timer mounted on a microcomputer;
a second step of converting an analog value sensed by a sensor into a digital value using an analog-to-digital converter;
a third step of storing the converted sensor data in an internal register of the microprocessor;
a fourth step of calculating the attitude and obtaining a coordinate conversion matrix using inclinometer data;
a fifth step of generating a virtual Z-axis earth magnetic data in the case of using a two-axis earth magnetic sensor;
a sixth step of calculating earth magnetic data on a horizontal coordinate system using a three-axis earth magnetic data (i.e., the two-axis earth magnetic sensor data plus the one-axis virtual sensor data) and the coordinate conversion matrix;
a seventh step of calculating the azimuth angle using the calculated data; and
an eighth step of, if a timer interrupt is generated due to the output period set in the internal timer, transmitting the sensor data and the calculated azimuth data to an external system through a serial communication and displaying the sensor data and the calculated azimuth data on an LCD module.

5. The method of claim 4, wherein an algorithm for generating the virtual Z-axis earth magnetic data comprises:

a first step of measuring by experiment a strength of an earth magnetic field measured when a measurement axis of the earth magnetic sensor points to a vertically downward direction of the earth;
a second step of calculating the attitude using an output of the inclinometer;
a third step of measuring the strength of the earth magnetic field sensed in X-axis (i.e., front) and Y-axis (i.e., right) directions of a sensor module using the two-axis earth magnetic sensor; and
a fourth step of generating the virtual Z-axis earth magnetic data using the calculated' attitude of the sensor module and an output value of the two-axis earth magnetic sensor.

6. The method of claim 5, wherein an algorithm for calculating the earth magnetic data on the horizontal coordinate system comprises:

a first step of calculating the coordinate conversion matrix using the attitude calculated using an output of the inclinometer; and
a second step of calculating the earth magnetic data of the horizontal coordinate system by multiplying the generated Z-axis earth magnetic data and the measured X-axis and Y-axis earth magnetic data by the calculated coordinate conversion matrix.

7. The method of claim 6, wherein an algorithm for calculating the azimuth information using the two-axis earth magnetic sensor comprises:

a first step of calculating the attitude using the inclinometer and obtaining the coordinate conversion matrix;

a second step of generating the virtual Z-axis earth magnetic data;
a third step of generating the earth magnetic data on the horizontal coordinate system; and
a fourth step of calculating the azimuth angle using X-axis and Y-axis data of the earth magnetic data on the horizontal coordinate system.

FIG. 1

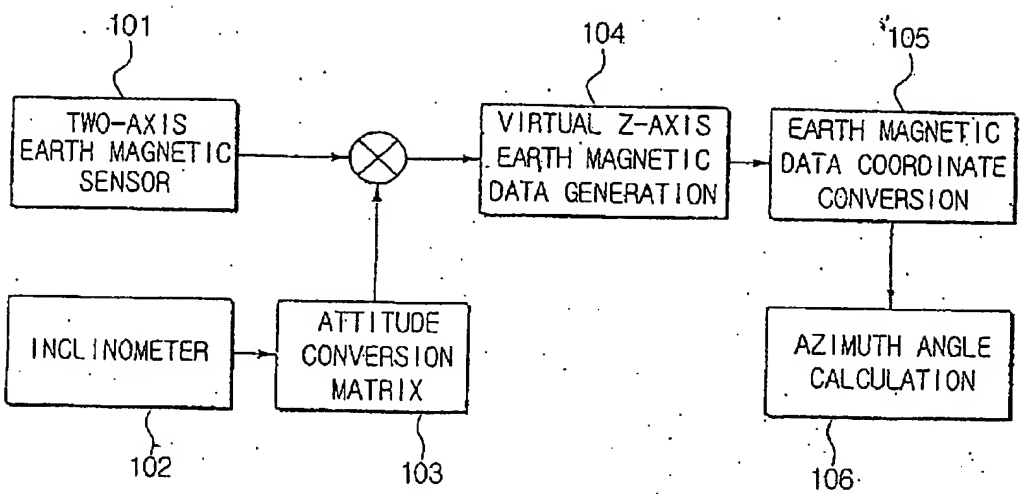
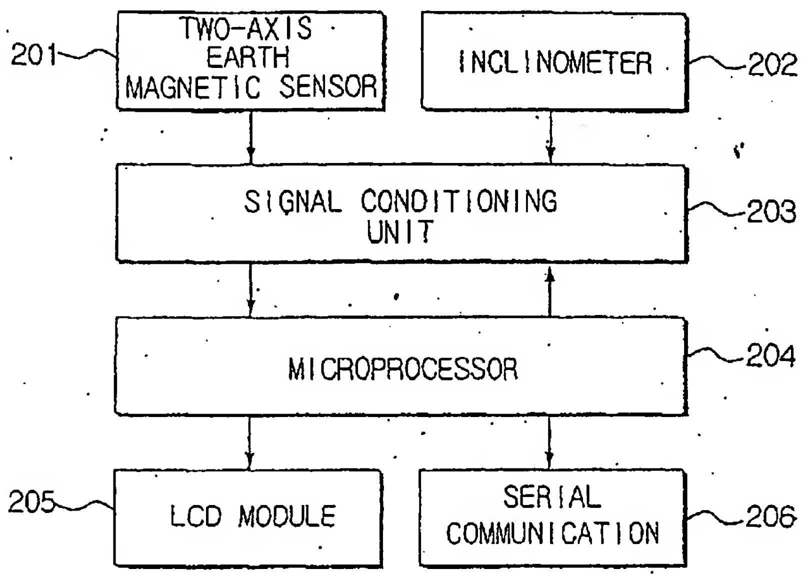

101
TWO-AXIS EARTH MAGNETIC SENSOR
104
VIRTUAL Z-AXIS EARTH MAGNETIC DATA GENERATION
105
EARTH MAGNETIC DATA COORDINATE CONVERSION
INCLINOMETER
102
ATTITUDE CONVERSION MATRIX
103
AZIMUTH ANGLE CALCULATION
106

FIG. 2



201
TWO-AXIS EARTH MAGNETIC SENSOR
INCLINOMETER
202
SIGNAL CONDITIONING UNIT
203
MICROPROCESSOR
204
205
LCD MODULE
SERIAL COMMUNICATION
206

FIG. 3

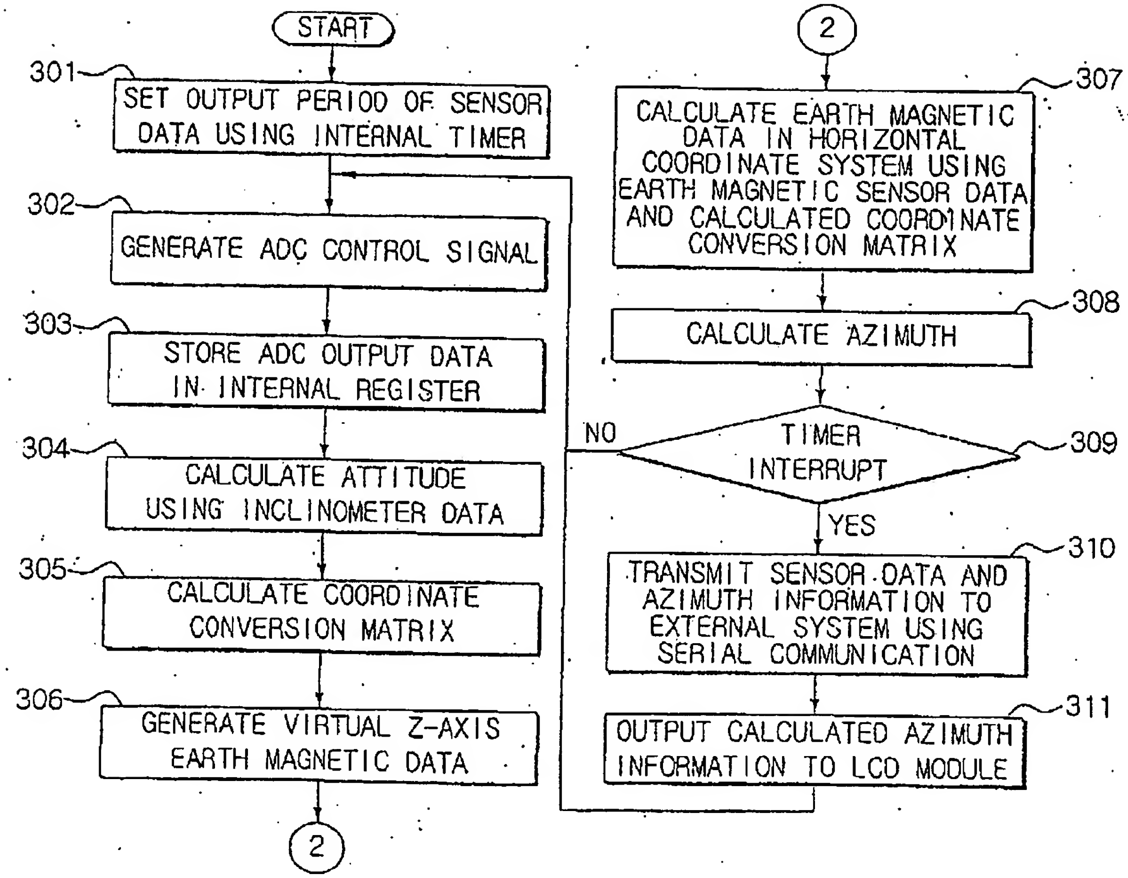

START
301
SET OUTPUT PERIOD OF SENSOR DATA USING INTERNAL TIMER
302
GENERATE ADC CONTROL SIGNAL
303
STORE ADC OUTPUT DATA IN INTERNAL REGISTER
304
CALCULATE ATTITUDE USING INCLINOMETER DATA
305
CALCULATE COORDINATE CONVERSION MATRIX
306
GENERATE VIRTUAL Z-AXIS EARTH MAGNETIC DATA
2
2
307
CALCULATE EARTH MAGNETIC DATA IN HORIZONTAL COORDINATE SYSTEM USING EARTH MAGNETIC SENSOR DATA AND CALCULATED COORDINATE CONVERSION MATRIX
308
CALCULATE AZIMUTH
309
TIMER INTERRUPT
NO
YES
310
TRANSMIT SENSOR DATA AND AZIMUTH INFORMATION TO EXTERNAL SYSTEM USING SERIAL COMMUNICATION
311
OUTPUT CALCULATED AZIMUTH INFORMATION TO LCD MODULE

FIG. 4

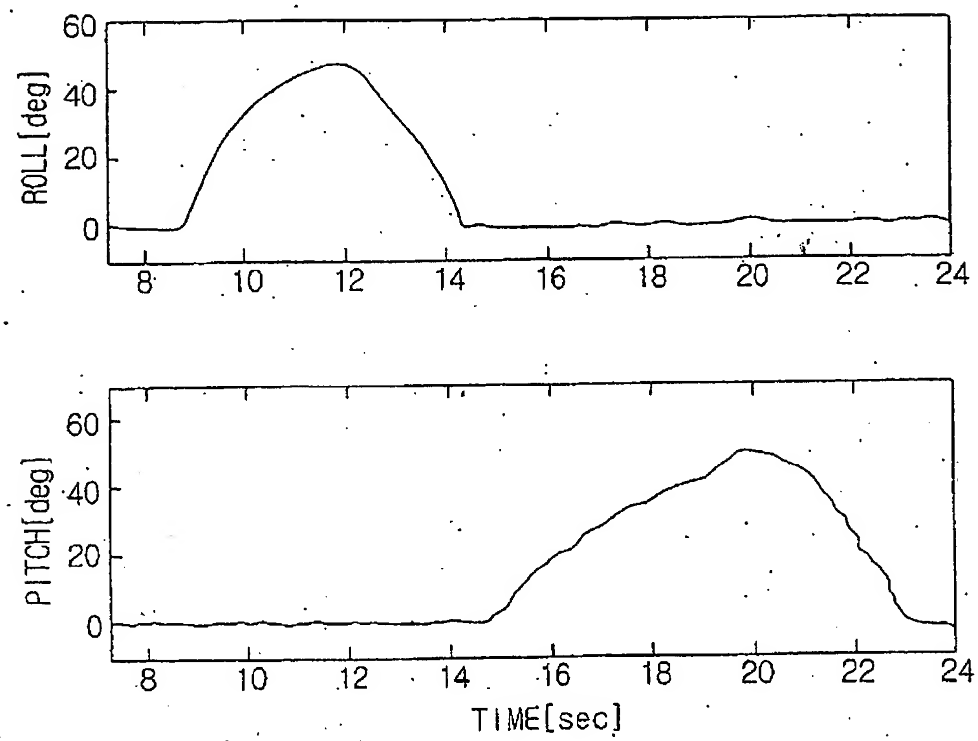

ROLL[deg]
60
40
20
0
8
10
12
14
16
18
20
22
24
PITCH[deg]
60
40
20
0
TIME[sec]

FIG. 5

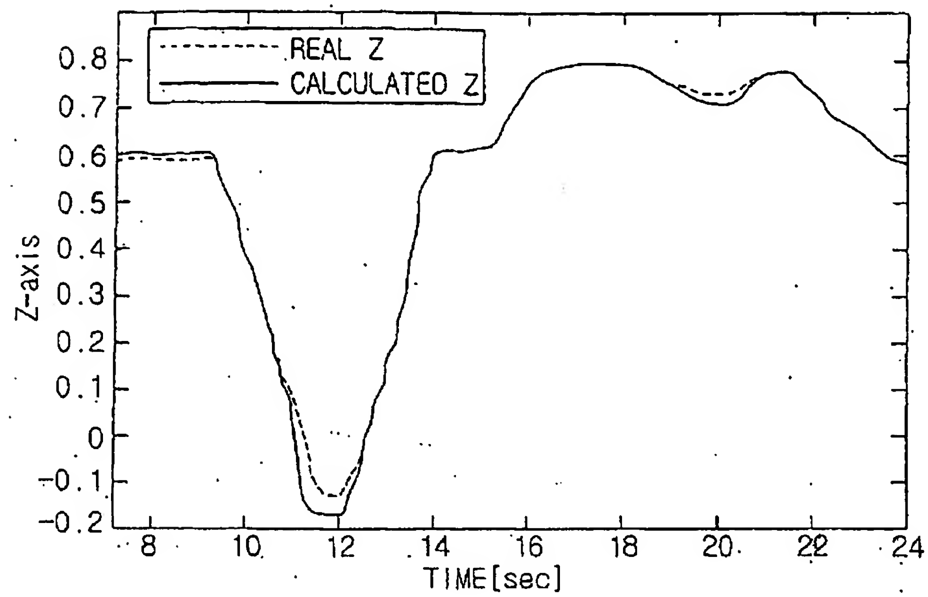
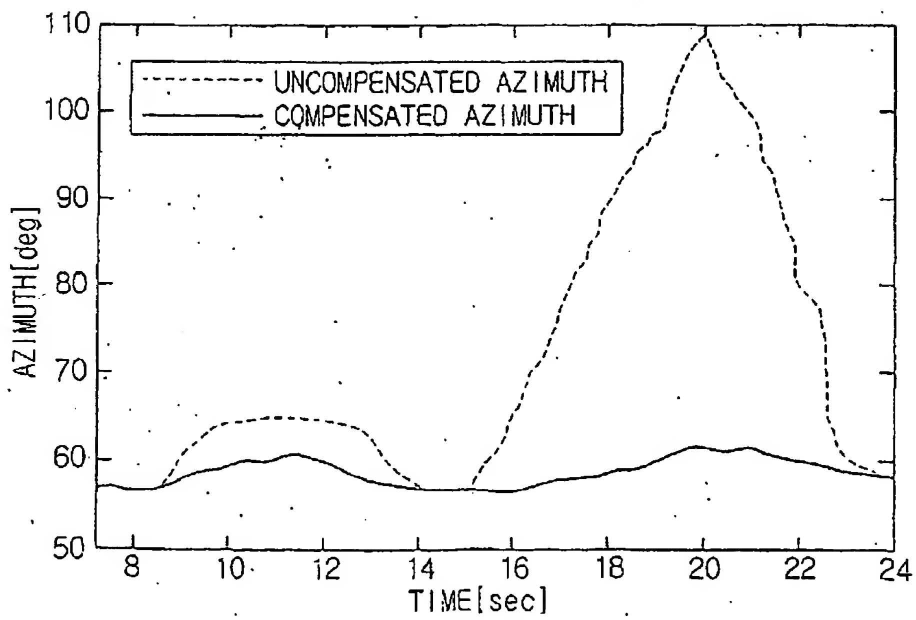

REAL Z
CALCULATED Z
Z-axis
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
8
10
12
14
16
18
20
22
24
TIME[sec]

FIG. 6


UNCOMPENSATED AZIMUTH
COMPENSATED AZIMUTH
AZIMUTH[deg]
110
100
90
80
70
60
50
8
10
12
14
16
18
20
22
24
TIME[sec]

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 25 4835

Category	DOCUMENTS CONSIDERED TO BE RELEVANT Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	US 4 414 753 A (MOULIN MICHEL ET AL) 15 November 1983 (1983-11-15) * column 1, line 8 - line 12 * * column 4, line 8 - line 20 * * column 11, line 53 - line 68 * * column 12, line 16 - line 59 * * column 15, line 50 - column 16, line 2 * * column 16, line 11 - line 61 * ---	1-7	G01C17/38
A	US 5 786 849 A (LYNDE C MACGILL) 28 July 1998 (1998-07-28) * column 2, line 20 - line 28 * * column 4, line 5 - line 14 * ---	1-3	
A	US 2002/092188 A1 (SMITH ROBERT B) 18 July 2002 (2002-07-18) * paragraph '0062! * -----	4-7	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7) G01C G01R

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	11 November 2003	de Bakker, M

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 03 25 4835

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The members are as contained in the European Patent Office EDP file on
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11-11-2003

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EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82